INTRODUCTION TO UNDERGROUND CABLES

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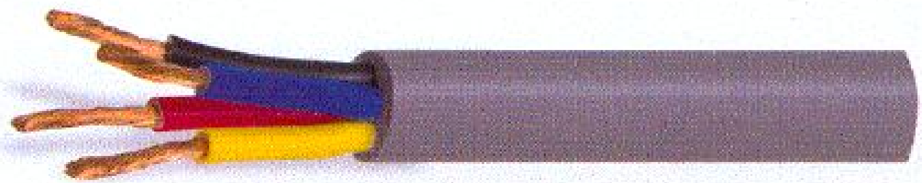
Cost ratio for double circuit installations

Voltage	132 kV	275 kV	400 kV
One km overhead line	51,000	136,000	262,000
One km underground	456,000	1,775,000	5,140,000
Ratio	9	13	20

Multicore Cables, with Flexible Copper Conductors PVC Insulated and PVC Sheathed

Description

- Soft annealed Copper fine wires, bunched together in sub units or stranded bunched groups into a main units, which forms the flexible conductor. These conductors are insulated with PVC compound rated 70 °C and sheathed with PVC compound layer.
- Cables are produced according to IEC 60227 or BS 6500.



Application

- For indoor movable installation in dry location connecting to source power portable electrical appliances operating under unfavorable conditions, such as portable lamps, fans, refrigerators, washing machines, vacuum cleaners, TV & house hold heating and ventilating apparatus.

Egytech - code	Number & cross sectional of conductors	Maximum diameter of wires	Max. Conductor resistance		Current rating in air		Approx. overall diameter	Approx. weight
			DC at 20 °C	AC at 70 °C	Lain in free air	Lain in conduits		
	nr x mm^2	mm	Ω/km	Ω/km	A	A	mm	kg/km
CPC-F102-U02	2 x 0.75	0.21	26.00	31.60	11	8	6.2	56
CPC-F102-U03	2 x 1.0	0.21	19.50	23.40	13	10	6.5	64
CPC-F102-U04	2 x 1.5	0.26	13.30	15.95	16	13	7.6	88
CPC-F102-U06	2 x 2.5	0.26	7.98	9.56	22	18	9.4	138

Multicore Cables, with Stranded Aluminium Conductors, PVC Insulated and PVC Sheathed

Description

- Multicore cables of stranded Aluminium conductors are insulated with PVC compound, assembled together, covered with overall jacket of PVC compound.
- Cables are produced according to IEC 60502 or BS 6346.

Application

- For outdoor and indoor installations in damp and wet locations.

Egytech - code	Nominal cross sectional area	Max. Conductor resistance		Current rating			Approx. overall diameter	Approx. weight
		DC at 20 °C	AC at 70 °C	Laid direct in ground	Laid in ducts	Laid in free air		
	mm²	Ω/km	Ω/km	A	A	A	mm	kg/km
Two core cables								
AP1-T102-U10	10 rm	3.080	3.300	46	39	46	15.8	360
AP1-T102-U11	16 rm	1.910	2.290	60	46	62	17.9	330
AP1-T102-U12	25 rm	1.200	1.440	77	60	81	21.3	435
AP1-T102-U13	35 rm	0.868	1.040	103	83	114	23.5	505
Three core cables								
AP1-T103-U10	10 rm	3.080	3.300	42	34	37	16.9	320
AP1-T103-U11	16 rm	1.910	2.290	53	42	50	19.0	405
AP1-T103-U12	25 rm	1.200	1.440	70	56	66	22.7	570

Multicore Cables, with Stranded, Aluminum Conductors, XLPE Insulated and PVC Sheathed

Description

- Multicore cables of stranded Aluminium conductors are insulated with XLPE compound, assembled together and covered with an overall jacket of PVC compound.
- Cables are produced according to IEC 60502 or BS 5467

Application

- For outdoor and indoor installations in damp and wet locations. They are normally used for power distribution in urban networks, in industrial plants, as well as in Thermopower and Hydropower stations.

Egytech - code	Nominal cross sectional area	Max. conductor resistance		Current rating			Approx. overall diameter	Approx. weight
		DC at 20 °C	AC at 90 °C	Laid direct in ground	Laid in ducts	Laid in free air		
	mm^2	Ω/km	Ω/km	A	A	A	mm	kg/km
Two core cables								
AX1-T102-U10	10 rm	3.080	3.950	57	48	55	14.7	335
AX1-T102-U11	16 rm	1.910	2.450	74	58	73	16.7	450
AX1-T102-U12	25 rm	1.200	1.540	97	75	97	20.1	640
AX1-T102-U13	35 rm	0.868	1.113	128	106	120	22.3	780

Three core cables

AX1-T103-U10	10 rm	3.080	3.950	52	42	48	15.6	375
AX1-T103-U11	16 rm	1.910	2.450	68	52	62	17.7	605
AX1-T103-U12	25 rm	1.200	1.540	90	71	84	21.4	835
AX1-T103-U13	35 rm	0.868	1.113	120	95	105	23.8	1050

Four core cables

AX1-T104-U10	10 rm	3.080	3.950	52	42	48	17.0	450
AX1-T104-U11	16 rm	1.910	2.450	68	52	62	19.4	700
AX1-T104-U12	25 rm	1.200	1.540	90	71	84	23.5	925
AX1-T104-U13	35 sm	0.868	1.113	120	95	110	23.6	800
AX1-T104-U14	50 sm	0.641	0.822	145	110	136	27.1	950
AX1-T104-U15	70 sm	0.443	0.569	175	140	168	31.4	1260
AX1-T104-U16	95 sm	0.320	0.411	210	165	205	35.1	1650
AX1-T104-U17	120 sm	0.253	0.325	235	190	236	39.2	2060
AX1-T104-U18	150 sm	0.206	0.265	265	215	278	43.7	2520
AX1-T104-U19	185 sm	0.164	0.212	290	240	315	48.7	3140
AX1-T104-U20	240 sm	0.125	0.163	340	280	378	54.5	4020
AX1-T104-U30	300 sm	0.100	0.131	390	315	446	60.1	4930

Four core cables with reduced neutral

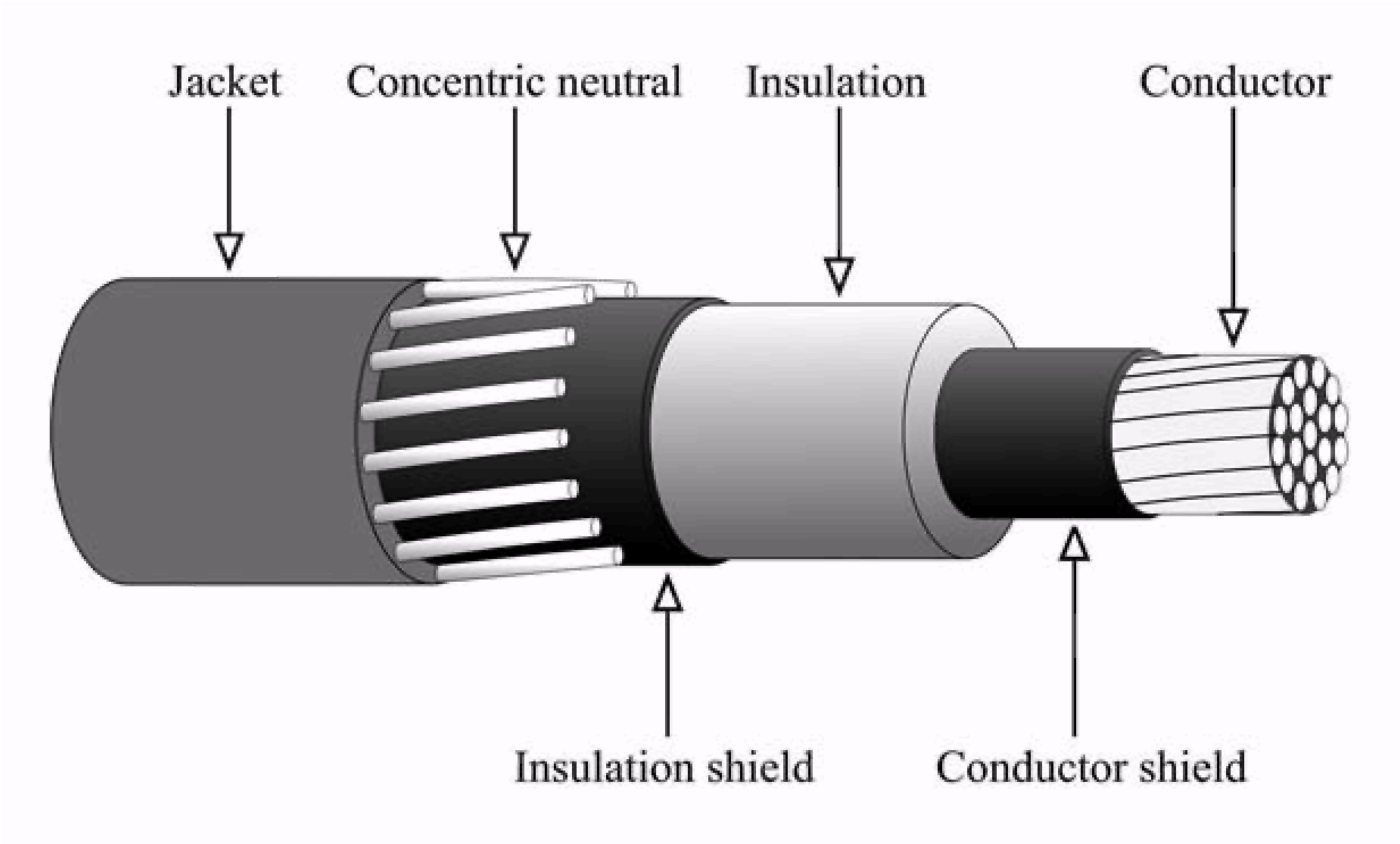
AX1-T105-U13	35 sm	16 rm	0.868/1.910	1.113/2.450	121	96	110	22.5	610
AX1-T105-U14	50 sm	25 rm	0.641/1.200	0.822/1.540	145	116	136	25.9	925
AX1-T105-U15	70 sm	35 sm	0.443/0.868	0.569/1.113	178	142	171	29.7	1255
AX1-T105-U16	95 sm	50 sm	0.320/0.641	0.411/0.822	214	171	211	33.6	1630
AX1-T105-U17	120 sm	70 sm	0.253/0.443	0.325/0.569	243	195	246	37.5	2030
AX1-T105-U18	150 sm	70 sm	0.206/0.443	0.265/0.569	272	220	282	41.3	2515
AX1-T105-U19	185 sm	95 sm	0.164/0.320	0.212/0.411	309	250	326	46.2	3095

(a)

(b)

Elements of typical (a) single-core and (b) three-core, steel armoured, insulated power cables.

Two main types of cable are available: concentric-neutral cable and power cable. Concentric-neutral cable normally has an aluminium conductor, an extruded insulation, and a concentric neutral.



Conductor Diameters

	Solid	Class B stranding	
Size	Diameter, in.	Strands	Diameter, in.
24	0.0201	7	0.023
22	0.0253	7	0.029
20	0.032	7	0.036
19	0.035	7	0.041
18	0.0403	7	0.046
16	0.0508	7	0.058

Cable Insulation

Paper

Natural rubbers (NR)

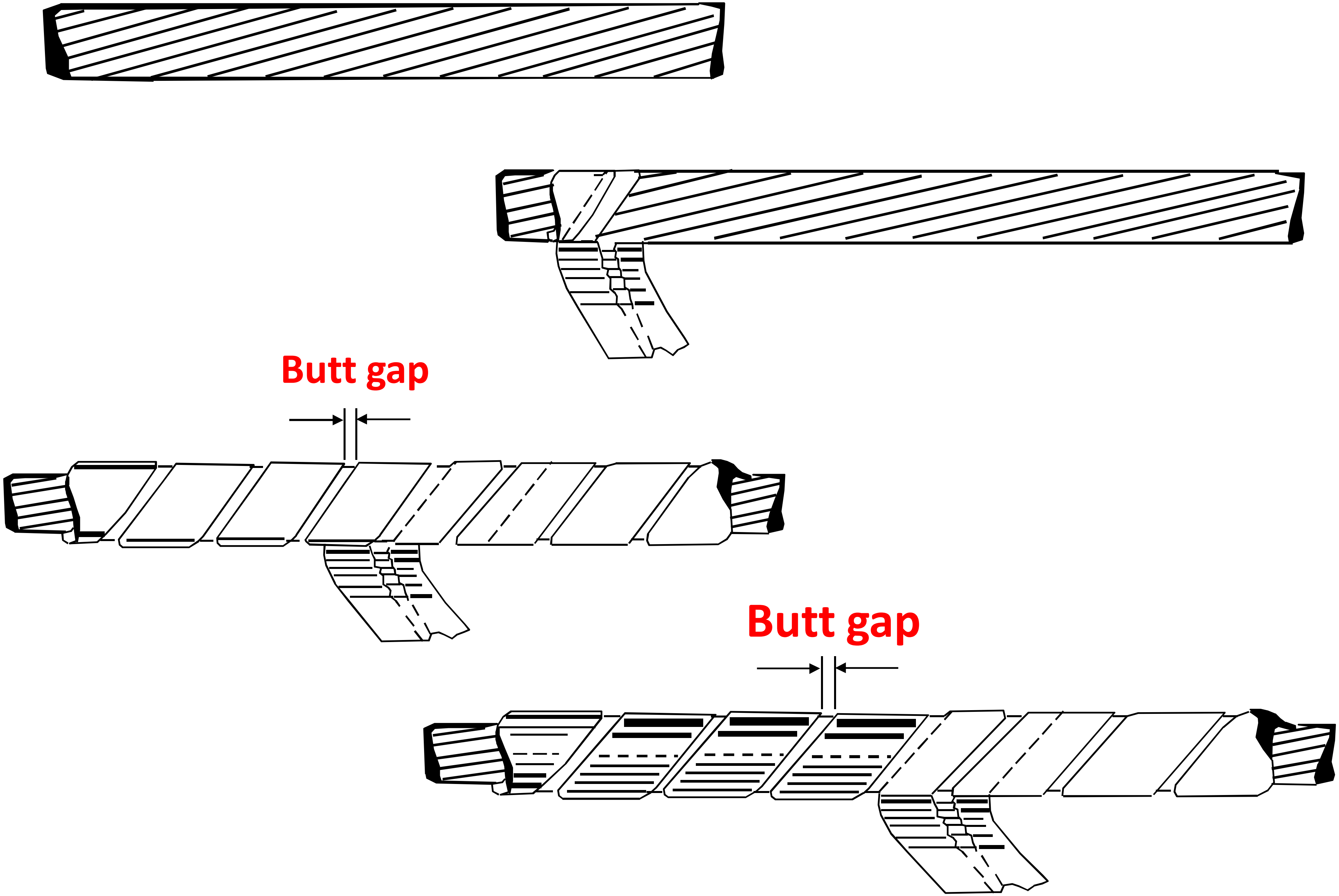
Silicone rubber (SR)

butyl rubber (BR)

Ethyl vinyl acetate (EVA)

Ethylene propylene (EP or EPR)

Cross-linked polyethylene *(XLP* or *XLPE)*


Butt gap
Butt gap

key properties of cable insulation

- **Dielectric constant "ε" (also called permittivity)**
- **Volume resistivity**
- **Dielectric losses**
- **Dissipation factor (also referred to as the loss angle, loss tangent, tan d, and approximate power factor):**

Semi-conducting Shield

Two layers of semiconductor material surround the metallic core

The first layer, placed directly around the conductor, has the following purposes

- To distribute the electric field uniformly around the conductor
- To prevent the formation of ionized voids in the conductor
- To dampen impulse currents travelling over the conductor surface

The second layer of semiconductor material is placed around the first insulating layer and has the following purposes

- **To reduce the surface voltage to zero**
- **To confine the electric field to the insulation, eliminating tangential stresses**
- **To offer a direct path to ground for short-circuit current if the shield is grounded**

Metallic Sheath

The metallic sheath surrounding insulated cables serves as an electrostatic shield, as a ground fault current conductor, and as a neutral wire

Armouring

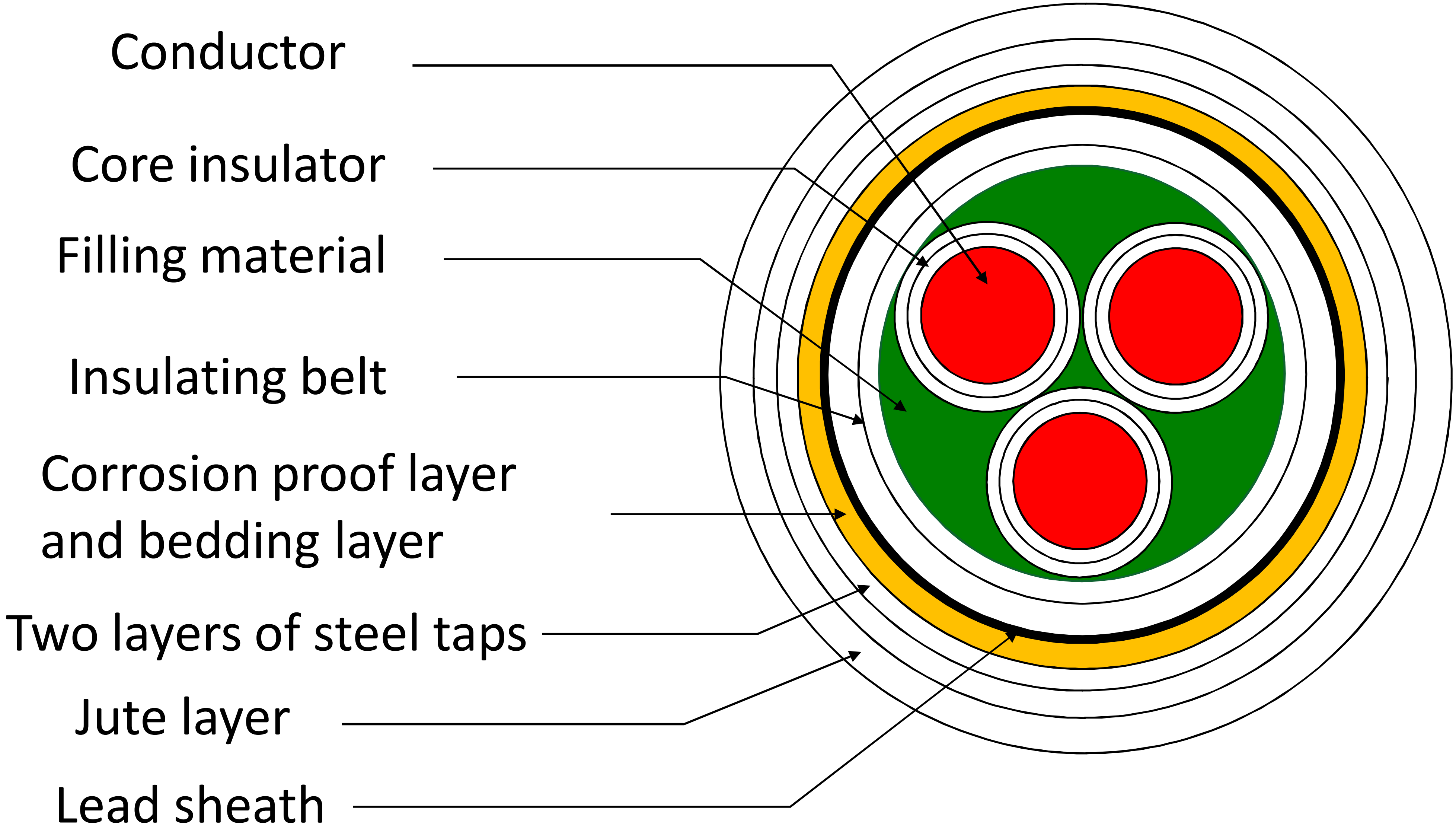
Paper-insulated lead-sheathed power cables are mechanically weak and normally protected against mechanical damage by steel armouring in the form of a double layer of steel tape or layers of steel wire. The lead sheath is separated from the steel armouring by two layers of paper taps followed by jute tapes or Hessian tapes. The materials separating the lead sheath and steel armouring are normally called bedding materials.

Armouring

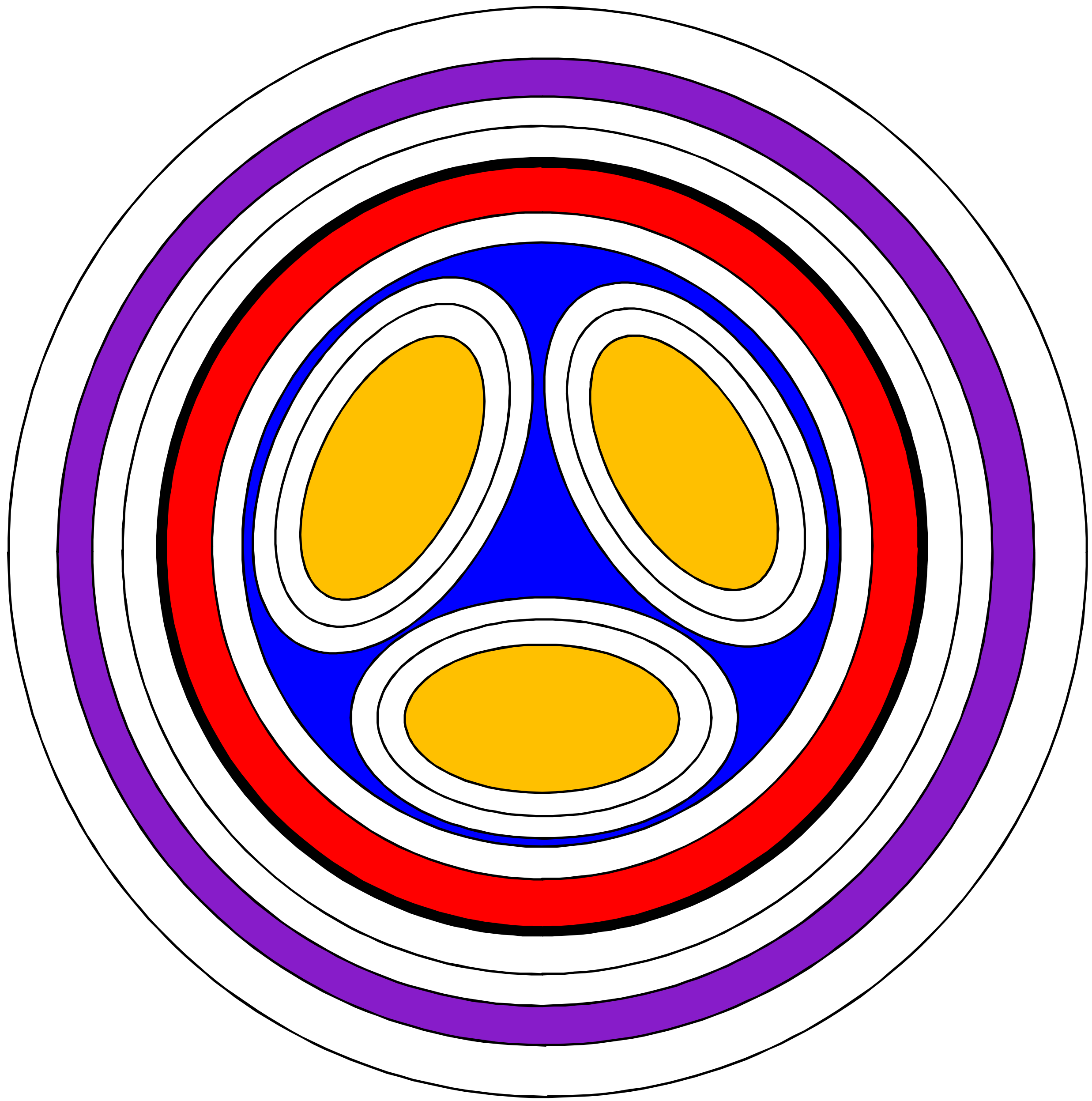
Aluminium-sheathed cables are not armoured except when special installation conditions are in a real need for it, such as underwater cables. The losses in the steel armour around a three-core cable may bring about a reduction in current-carrying capacity of the order of 5%.

External Layer

External layer provide mechanical protection against the environment during installation and operation. Commonly used materials are PVC and polyethylene due to their ability to withstand the cable operating temperature, their resistance to excessive degradation when in contact with chemicals actions, and their excellent mechanical properties for undergoing stresses during transportation, or compression and tension during installation and operation.


Conductor
Core insulator
Filling material
Insulating belt
Corrosion proof layer
and bedding layer
Two layers of steel taps
Jute layer
Lead sheath

Oval conductor



Underground Layout and Construction

Direct Buried Cables

Underground distribution power cables can be installed directly in a trench (direct burial) or in a duct

In some instances, power cables can be installed with telephone, gas, water, or other facilities

Direct burial of power cables is commonly used in low-density residential areas

The main advantage of direct burial installation is its low cost

Cable in Ducts

Ducts or conduits are normally used under roadways, or in locations where mechanical or other types of damage may be expected. Conduit installation is expensive and complex and the conduit type should be selected carefully

Manholes

Manholes are typically built at the splices as a way for workers to install cables or other equipment, provide test points, and perform routine or maintenance

The dimensions of the manholes should accommodate the conduits and cables entering the manhole and any equipment installed, such as transformers or protective equipment

Manholes

Partial Discharge Test

Gas-filled voids are found in the insulation and at the juncture of dielectric and conductive sheaths of cables

The breakdown of this gas produces a phenomenon known as partial discharge

Partial discharge occurs at these voids because the breakdown strength of the gas within voids is much less than that of the typical cable insulation material

In fact, discharges may occur at voltages lower than the operating voltage of the cable

The level of voltage at which partial discharge occurs first is called the discharge inception voltage

Overview of Electric Parameters of Underground Power Cables

Cable Electrical Resistance

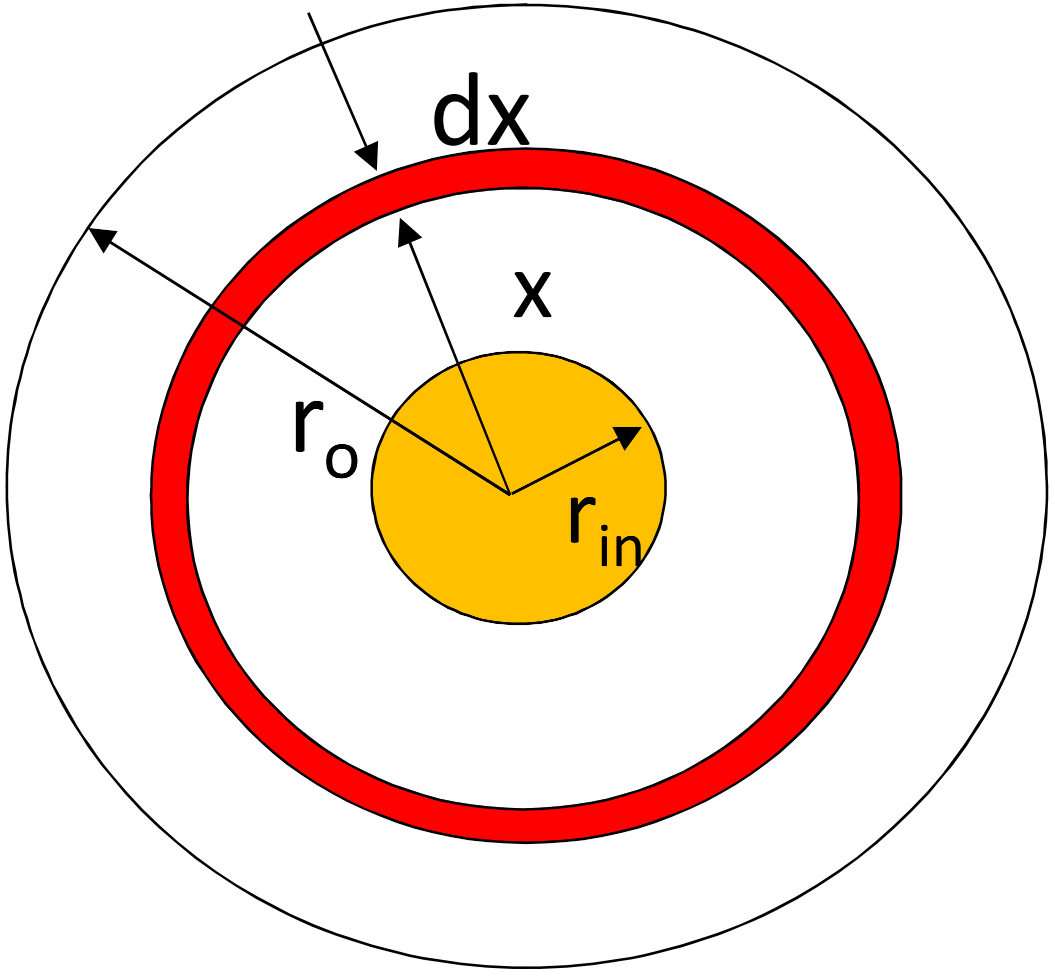
$$\boxed{R_{t_c} = R_{20}\left[1 + \alpha_{20}\left(t_c - 20\right)\right]}$$

Insulation Resistance of Single-Core Cables

$$dR = \frac{\rho dx}{2\pi x L}$$

$$R = \int_{r_{in}}^{r_o} \frac{\rho dx}{2\pi x L}$$

$$= \frac{\rho}{2\pi L} \log \frac{r_o}{r_{in}}$$



Capacitance and Electric Stress of Single-core Cables

$$V = \frac{Q}{2\pi\varepsilon_0\varepsilon_r}\log\frac{r_o}{r_{in}}$$

$$C = \frac{2\pi\varepsilon_0\varepsilon_r}{\log\frac{r_o}{r_{in}}}$$

$$E_{r_{in}} = \frac{V}{r_{in}\log\frac{r_o}{r_{in}}}$$

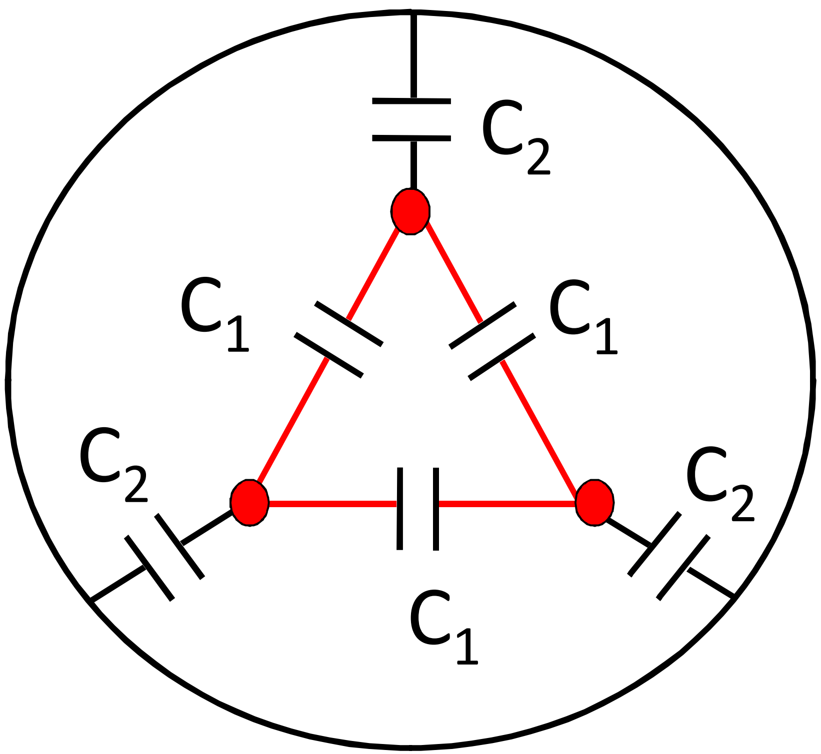
$$E_{r_o} = \frac{V}{r_o\log\frac{r_o}{r_{in}}}$$

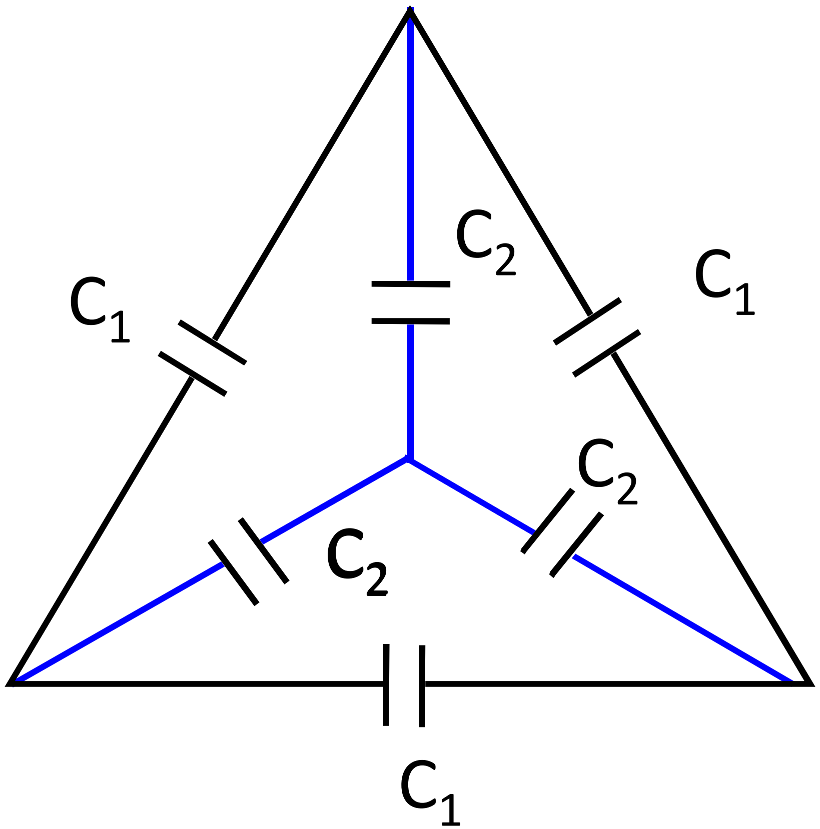
$$\frac{E_{max}}{E_{min}} = \frac{E_{r_{in}}}{E_{r_o}} = \frac{r_o}{r_{in}}$$

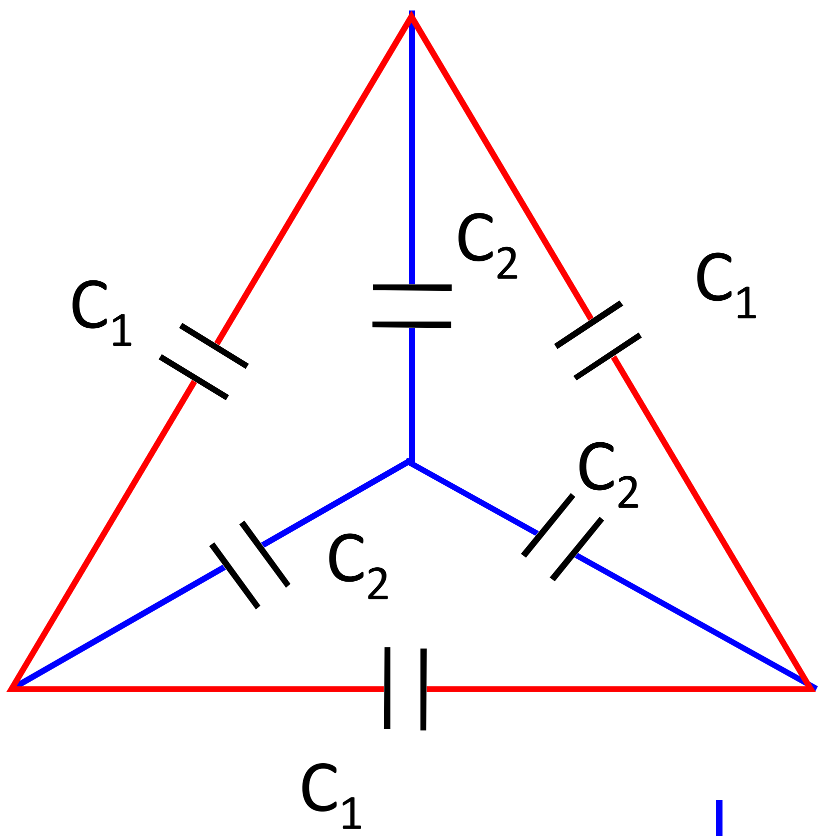
For given values of "E" and "r_o", there is a certain value of the conductor radius "r_{in}", which gives a **minimum electrical stress** at the conductor surface. This value is given by the relation:

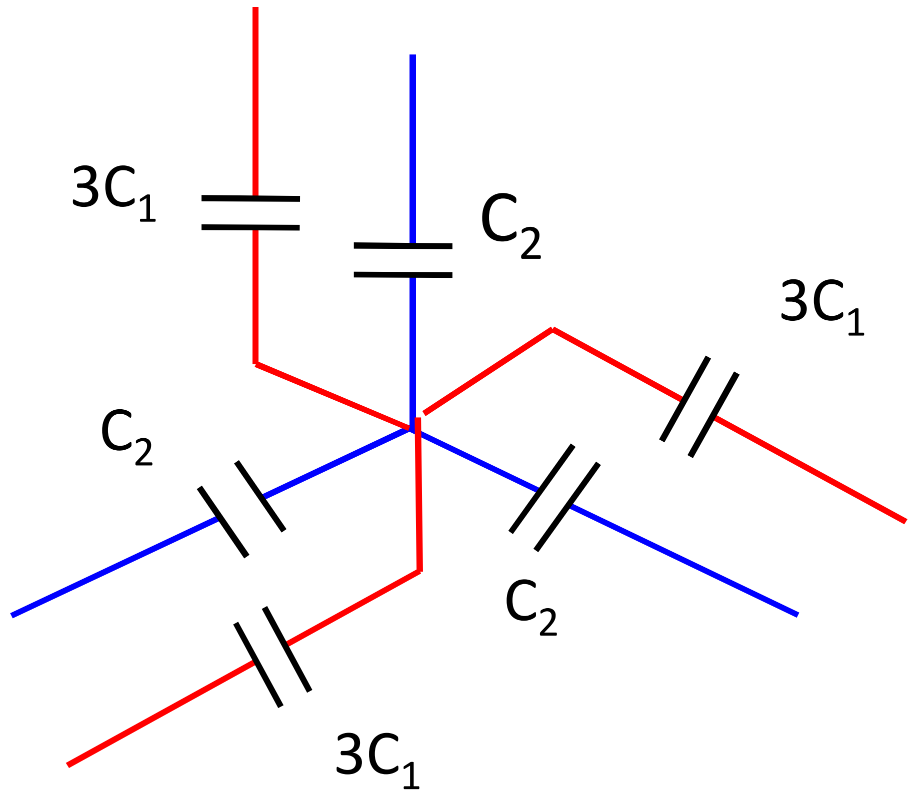
$$\boxed{\frac{r_o}{r_{in}} = e = 2.718}$$

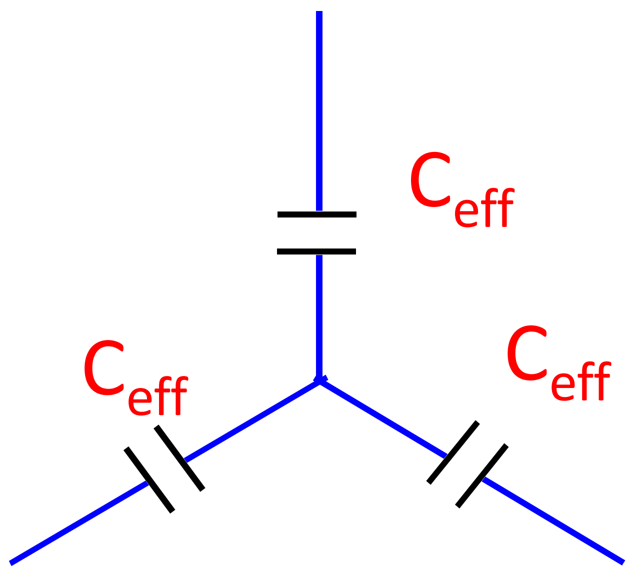
Capacitance of 3-core Belted type Cables







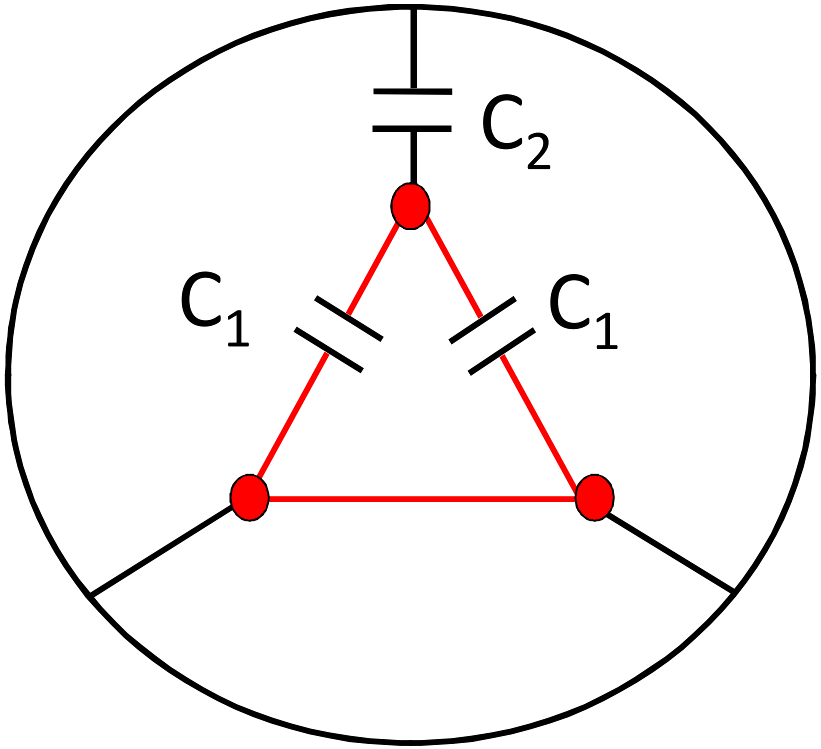


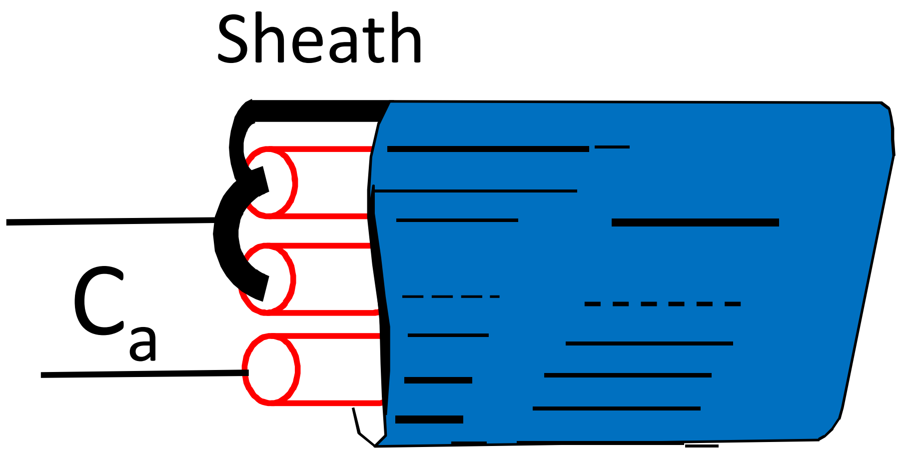


$$C_{eff} = 3C_1 + C_2$$

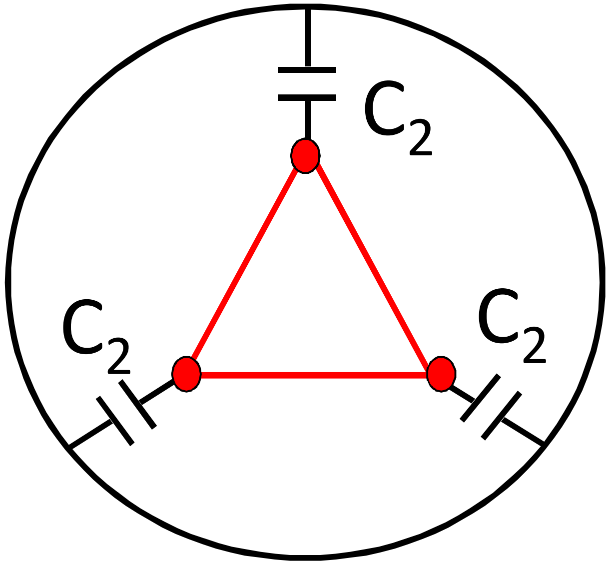
The capacitances C_1 and C_2 are determined by two measurements:

(a) the capacitance C_a between conductor 1 and the other two conductors joined together to the sheath, where $C_a = C_2 + 2C_1$

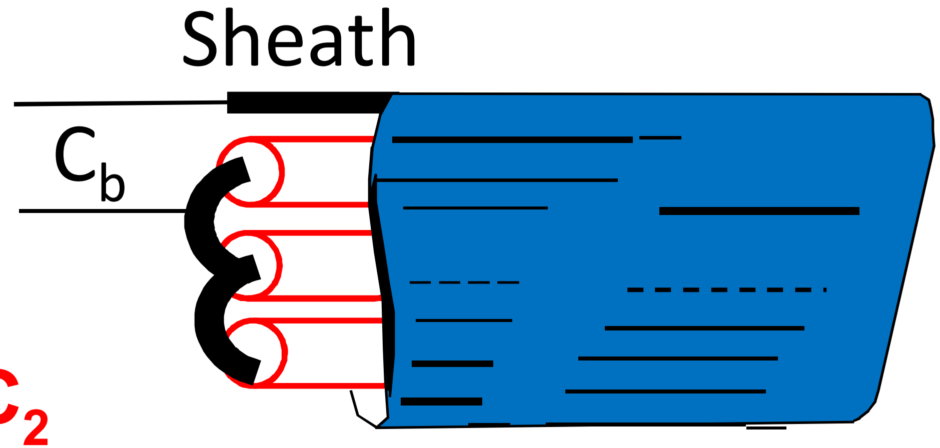




(b) the capacitance C_b between the sheath and all the three conductors joined together, where



$$C_b = 3\,C_2$$



From these values, the effective capacitance to neutral is given as follows:

$$C = \frac{9C_a - C_b}{6}$$

Grading of Cables

The permissible operating voltage is governed by the max. electrical stress at the conductor surface, while the major bulk of insulation remains under stressed

Economical cable has reduced insulation thickness and overall diameter by maintaining the electrical stress constant through the insulation.

It is impossible to have a constant stress, but the ratio E_{max} / E_{min} can be reduced.

Either one of the two following methods can achieve this target:

Capacitance grading

Intersheath grading

Capacitance grading

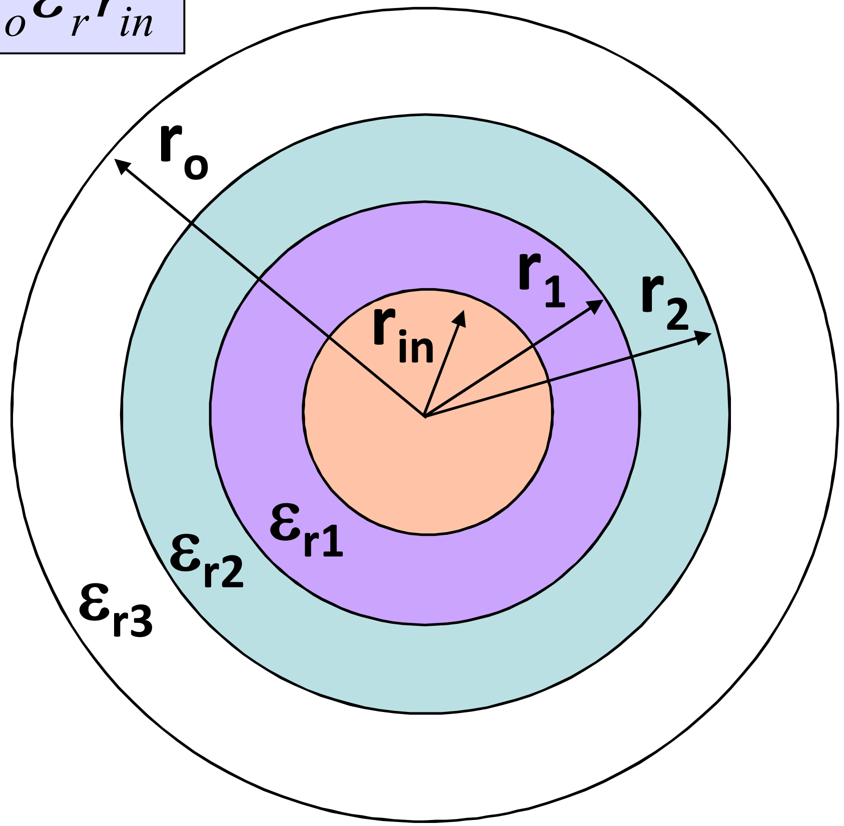
Use dielectric layers with different permittivities

$$E_x = \frac{Q}{2\pi\varepsilon_o\varepsilon_r x}$$

$$E_{max} = E_{r_{in}} = \frac{Q}{2\pi\varepsilon_o\varepsilon_r r_{in}}$$

$$If \quad \varepsilon_r \propto \frac{1}{x} = \frac{k}{x}$$

$$E_x = \frac{Q}{2\pi\varepsilon_o\left(\frac{k}{x}\right)x}$$ **= constant**



Capacitance grading

$$E_1 = \frac{Q}{2\pi\varepsilon_o\varepsilon_{r_1} r_{in}}$$

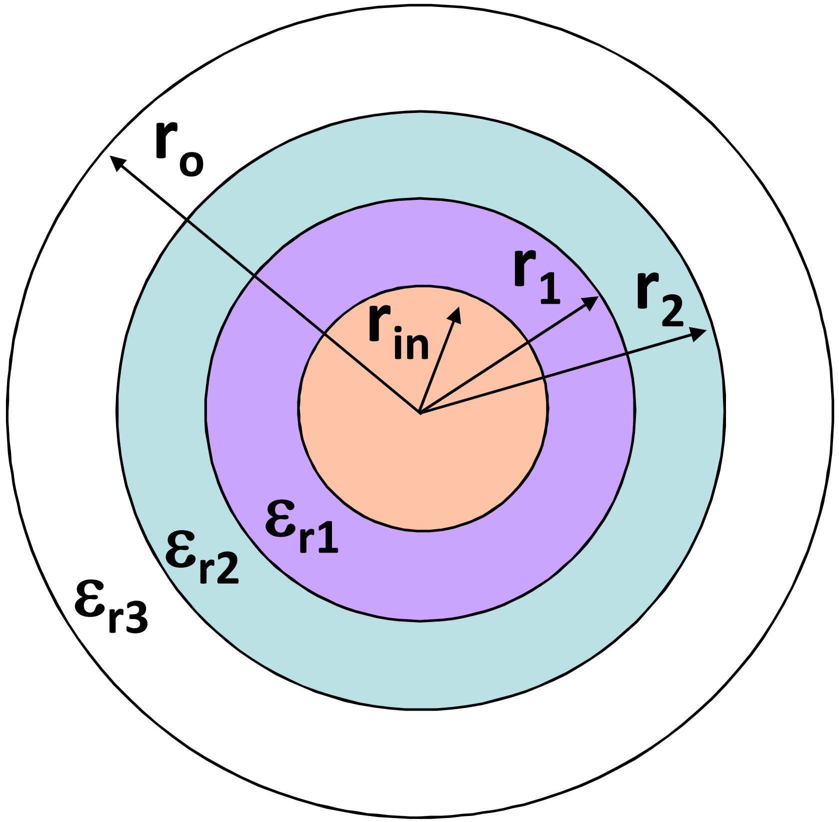
$$E'_1 = \frac{Q}{2\pi\varepsilon_o\varepsilon_{r1} r_1}$$

$$E_2 = \frac{Q}{2\pi\varepsilon_o\varepsilon_{r_2} r_1}$$

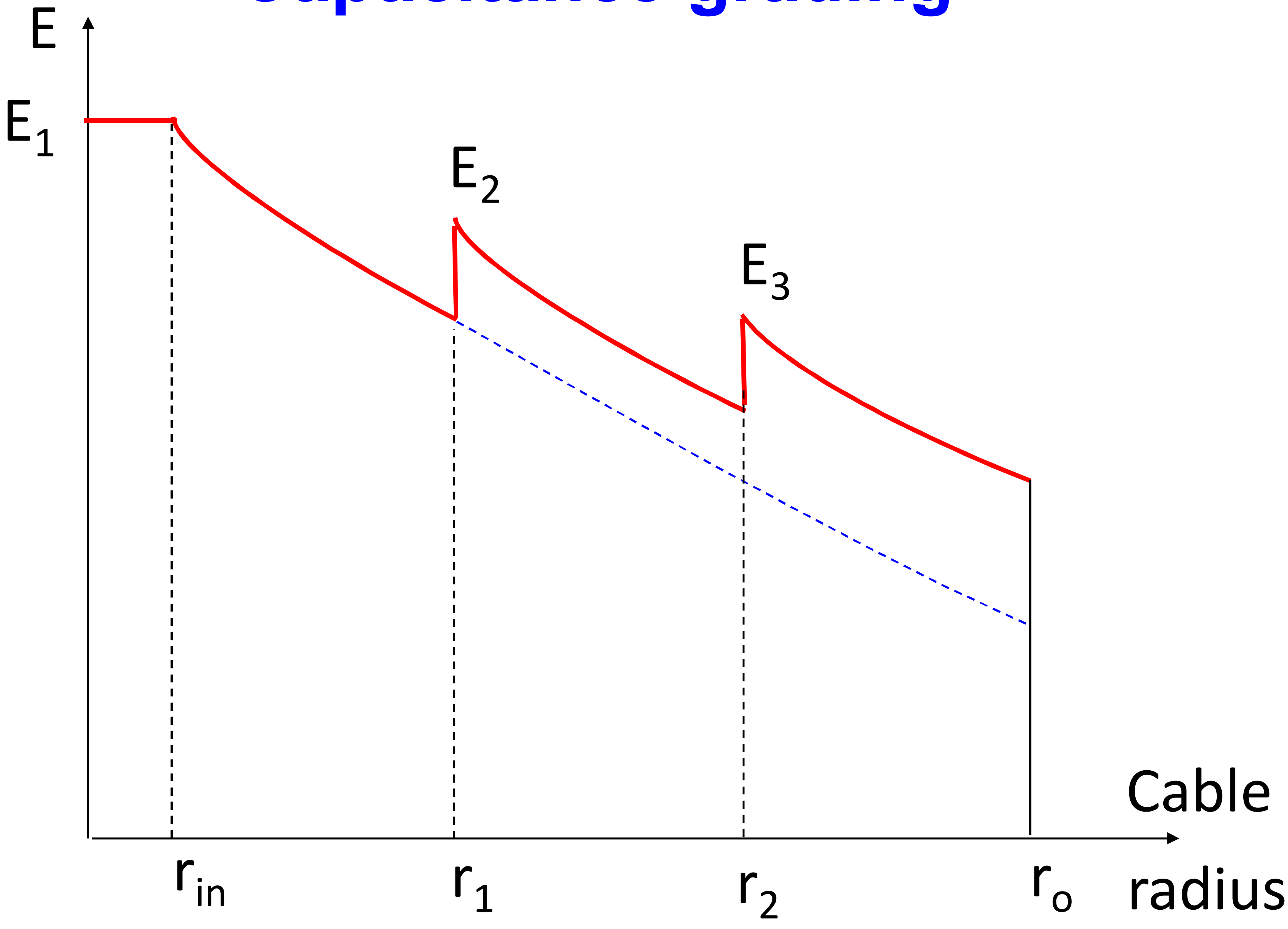
$$E'_2 = \frac{Q}{2\pi\varepsilon_o\varepsilon_{r_2} r_2}$$

$$E_3 = \frac{Q}{2\pi\varepsilon_o\varepsilon_{r_3} r_2}$$

$$E'_3 = \frac{Q}{2\pi\varepsilon_o\varepsilon_{r3} r_o}$$



Capacitance grading



Capacitance grading

Let E_{b1}, E_{b2}, E_{b3} be the breakdown strengths of the three materials.

$$E_1 = \frac{Q}{2\pi\varepsilon_o\varepsilon_{r_1} r_{in}} = \frac{E_{b_1}}{\mathrm{f}}$$

$$E_2 = \frac{Q}{2\pi\varepsilon_o\varepsilon_{r_2} r_1} = \frac{E_{b_2}}{\mathrm{f}}$$

$$E_3 = \frac{Q}{2\pi\varepsilon_o\varepsilon_{r_3} r_2} = \frac{E_{b_3}}{\mathrm{f}}$$

f : safety factor

Capacitance grading

$$\boxed{\varepsilon_{r1} r_{in} E_{b1} = \varepsilon_{r2} r_1 E_{b2} = \varepsilon_{r3} r_2 E_{b2}}$$

$r_{in} < r_1 < r_2$

$$\boxed{\varepsilon_{r1} E_{b1} > \varepsilon_{r2} E_{b2} > \varepsilon_{r3} E_{b2}}$$

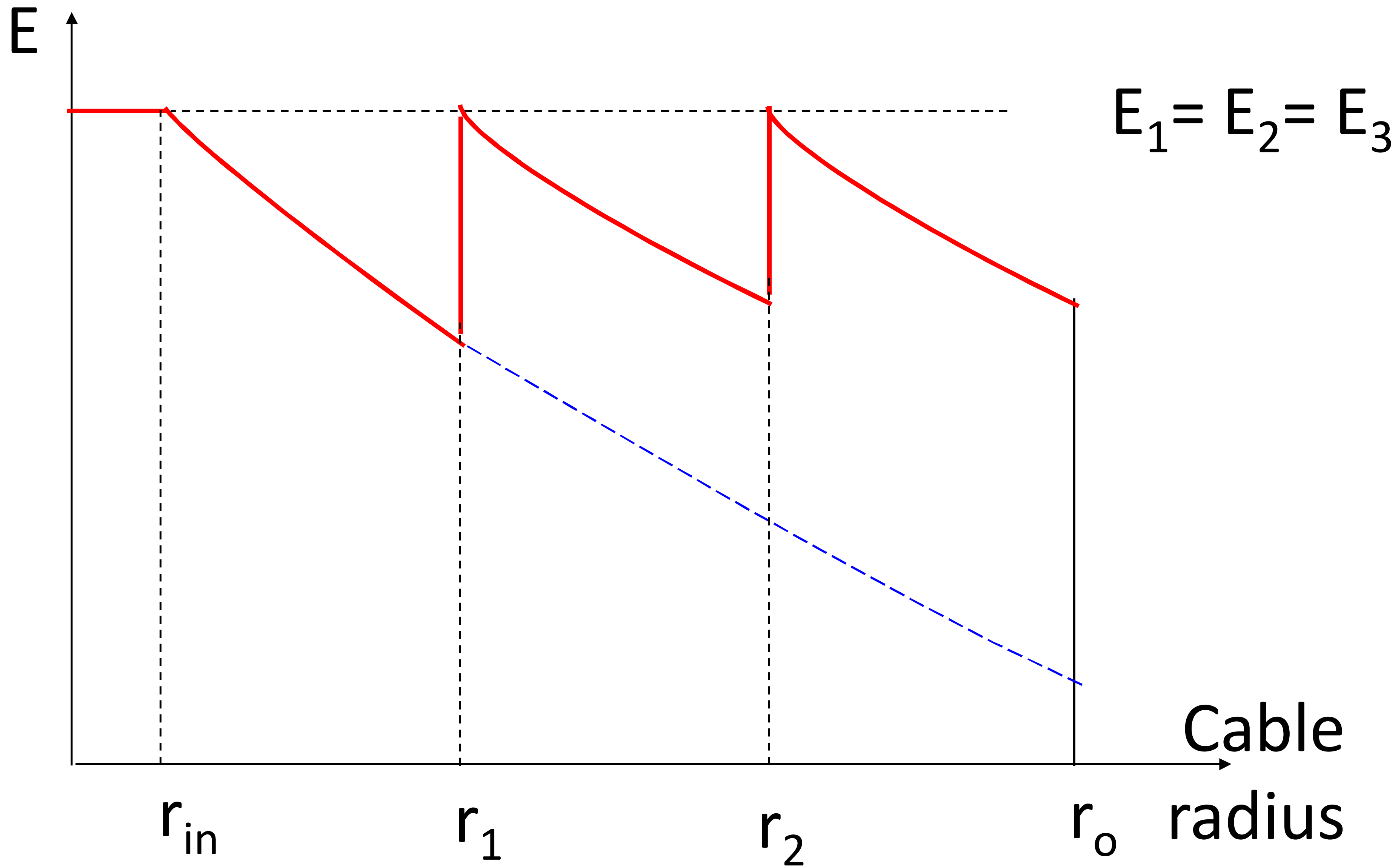
Capacitance grading

The potential difference between the conductor and the sheath

$$V = \int_{r_{in}}^{r_1} \frac{Q}{2\pi\varepsilon_o\varepsilon_{r1} x} dx + \int_{r_1}^{r_2} \frac{Q}{2\pi\varepsilon_o\varepsilon_{r2} x} dx + \int_{r_2}^{r_o} \frac{Q}{2\pi\varepsilon_o\varepsilon_{r3} x} dx$$

$$V = \frac{Q}{2\pi\varepsilon_o}\left[\frac{1}{\varepsilon_{r1}} log\frac{r_1}{r_{in}} + \frac{1}{\varepsilon_{r2}} log\frac{r_2}{r_1} + \frac{1}{\varepsilon_{r3}} log\frac{r_o}{r_3}\right]$$

Capacitance grading



Capacitance grading

$$E_1 = \frac{Q}{2\pi\varepsilon_o \varepsilon_{r_1} r_{in}}$$

$$V = \frac{Q}{2\pi\varepsilon_o}\left[\frac{1}{\varepsilon_{r1}} log \frac{r_1}{r_{in}} + \frac{1}{\varepsilon_{r2}} log \frac{r_2}{r_1} + \frac{1}{\varepsilon_{r3}} log \frac{r_o}{r_3}\right]$$

$$E_1 = \frac{V}{\varepsilon_{r1} r_{in}\left[\frac{1}{\varepsilon_{r1}} log \frac{r_1}{r_{in}} + \frac{1}{\varepsilon_{r2}} log \frac{r_2}{r_1} + \frac{1}{\varepsilon_{r3}} log \frac{r_o}{r_3}\right]}$$

Capacitance grading

If the three materials are to have the same maximum electrical stress, i.e. $E_l = E_2 = E_3 = E_{max}$

$$\varepsilon_{r1} r_{in} = \varepsilon_{r2} r_1 = \varepsilon_{r3} r_2$$

$$\varepsilon_{r1} > \varepsilon_{r2} > \varepsilon_{r3}$$

$$V_1 = \int_{r_1}^{r_{in}} E_x dx = \int_{r_{in}}^{r_1} \frac{Q}{2\pi\varepsilon_o\varepsilon_{r_1} x} dx = \frac{Q}{2\pi\varepsilon_o\varepsilon_{r_1}} \log\frac{r_1}{r_{in}}$$

$$= \frac{Q}{2\pi\varepsilon_o\varepsilon_{r_1} r_{in}} r_{in} \log\frac{r_1}{r_{in}} = E_{\max} r_{in} \log\frac{r_1}{r_{in}}$$

Capacitance grading

$$V_1 = E_{\max} r_{in} \log \frac{r_1}{r_{in}}$$

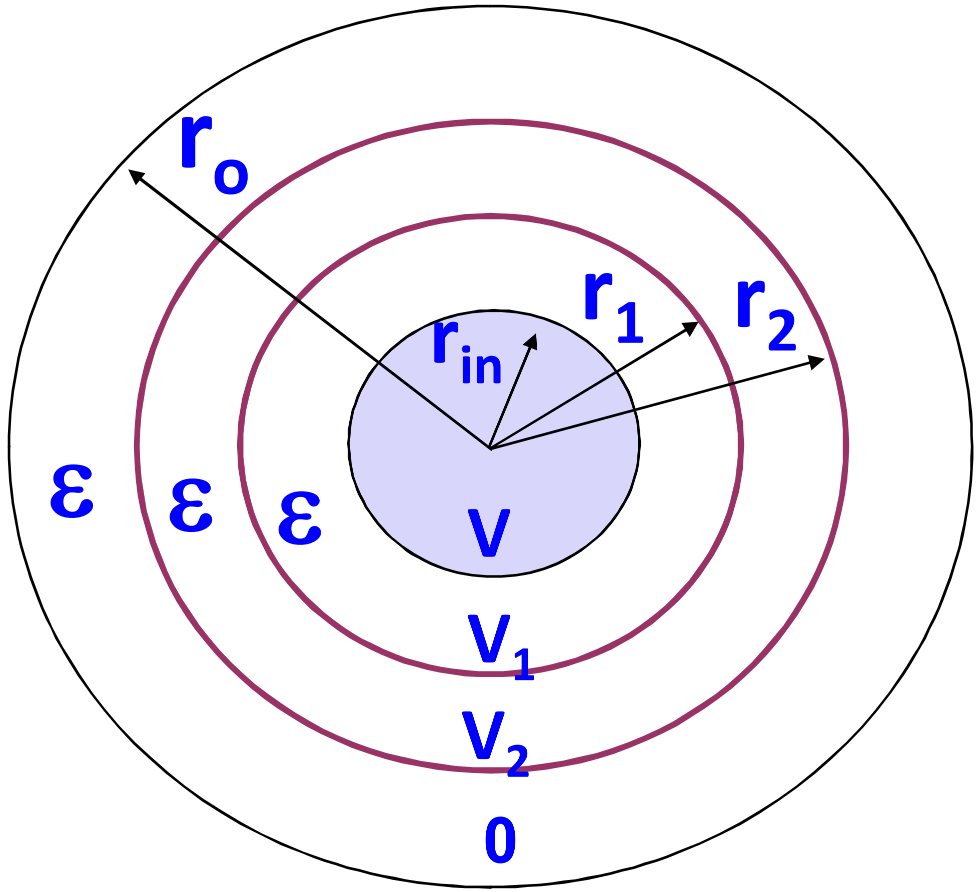
$$V_2 = E_{max} r_1 \, log \frac{r_2}{r_1}$$

$$V_3 = E_{max} r_2 \, log \frac{r_o}{r_2}$$

$$V = V_1 + V_2 + V_3 = E_{max}\left(r_{in} \, log \frac{r_1}{r_{in}} + r_1 \, log \frac{r_2}{r_1} + r_2 \, log \frac{r_o}{r_2} \right)$$

Intersheath grading

In this case, a single dielectric is used, but is separated into two or more layers by **thin metallic intersheaths** maintained at the appropriate potentials by connecting them to tapping on the winding of the transformer supplying the cable.



Intersheath grading

$$E_{1_{\max}} = \frac{V - V_1}{r_{in}\log\frac{r_1}{r_{in}}}$$

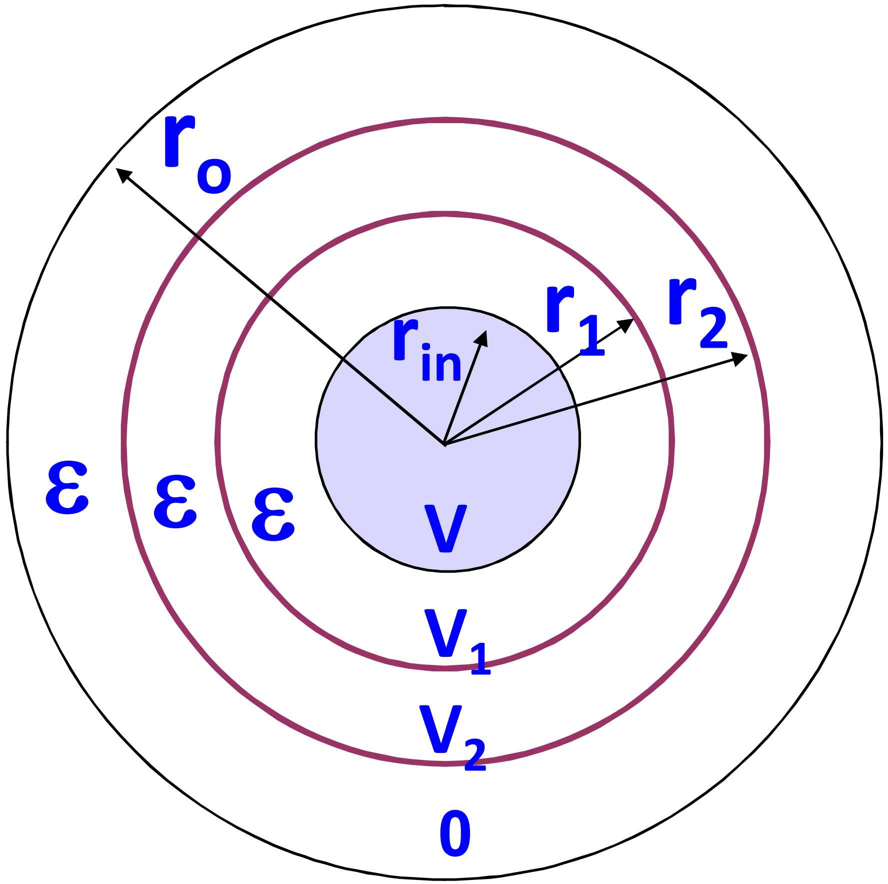
$$E_{1_{\min}} = \frac{V - V_1}{r_1\log\frac{r_1}{r_{in}}}$$

$$E_{2_{\max}} = \frac{V_1 - V_2}{r_1\log\frac{r_2}{r_1}}$$

$$E_{2_{\min}} = \frac{V_1 - V_2}{r_2\log\frac{r_2}{r_1}}$$

$$E_{3_{\max}} = \frac{V_2}{r_2\log\frac{r_o}{r_2}}$$

$$E_{3_{\min}} = \frac{V_2}{r_o\log\frac{r_o}{r_2}}$$



Intersheath grading

Since the dielectric is the same throughout the cable, it is desired to have the same E_{max} and E_{min} throughout the different layers

$$\frac{E_{max}}{E_{min}} = \frac{r_1}{r_{in}} = \frac{r_2}{r_1} = \frac{r_o}{r_2} = \alpha$$

where $\alpha > 1$

$$r_1 = \alpha r_{in} \qquad r_2 = \alpha r_1 = \alpha^2 r_{in} \qquad r_o = \alpha r_2 = \alpha^2 r_1 = \alpha^3 r_{in}$$

$$E_{max} = \frac{V - V_1}{r_{in} \log \alpha} = \frac{V_1 - V_2}{\alpha r_{in} \log \alpha} = \frac{V_2}{\alpha^2 r_{in} \log \alpha}$$

Intersheath grading

$$E_{max} = \frac{V - V_1}{r_{in}\, log\, \alpha} = \frac{V_1 - V_2}{\alpha r_{in}\, log\, \alpha} = \frac{V_2}{\alpha^2 r_{in}\, log\, \alpha}$$

[redacted]

$$r_o = \alpha r_2 = \alpha^2 r_1 = \alpha^3 r_{in}$$

$$E_{\max} = \frac{V}{\left[1 + \alpha + \alpha^2\right] r_{in} \log \alpha} = \frac{V}{\frac{\mathbf{1}}{\mathbf{3}} r_{in} \left[1 + \alpha + \alpha^2\right] \log \frac{r_o}{r_{in}}}$$

Intersheath grading

If the same cable (core radius r_{in} and internal sheath radius r_o) were not graded, the maximum electrical stress would be

$$E'_{max} = V / r_{in} \, log \frac{r_o}{r_{in}}$$

$$E'_{max} = \frac{1}{3}\left(1 + \alpha + \alpha^2\right)E_{max}$$

$$E'_{max} > E_{max}$$

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